In-flight diagnostics in LISA PathFinder

Alberto Lobo
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<u>For the Spanish *LPF* team:</u>

Thermal:

- **Juan Ramos**, *UPC*
- Pep Sanjuan, *IEEC*
- Miquel Nofrarias, *IEEC*
- Alberto Lobo, *CSIC & IEEC*

Magnetic:

- **Lluís Martínez**, *Atipic*
- Sergi García, *Atipic*

Radiation Monitor:

- **Mokhtar Chemeissani**, *IFAE*
- César Boatella, *IEEC*
- Carles Puigendoles, *IFAE*
- Henrique Araujo, *ICL*
- Peter Wass, *ICL*
- Catia Grimani, *Univ. Urbino*

Software:

- **Joan Clua**, *NTE*
- José Antonio Ortega, *IEEC*
- Xevi Xirgu, *IEEC*
- Aleix Conchillo, *IEEC*
- Héctor García, *NTE*

Management:

- **Ivan Lloro**, PM, *IEEC*
- Josep Colomé, Doc, *IEEC*
- Albert Tomàs, SE, *NTE*
- Xavi Llamas, SM, *NTE*
- Sònia Ferrer, PA, *NTE*

PI:

- **Alberto Lobo**, *CSIC & IEEC*

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Why is diagnostics analysis needed in the LTP

LISA's top level sensitivity requirement is:

***LISA*:**

$$S_{\Delta a}^{1/2}(\omega) = 3\times10^{-15}\left[1+\left(\frac{f}{3\ \mathrm{mHz}}\right)^2\right]\ \frac{m}{s^2}\,\mathrm{Hz}^{-1/2}\ ,\qquad 0.1\ \mathrm{mHz}\le f\le 0.1\ \mathrm{Hz}$$

This is so very demanding a previous *LPF* mission is planned, with a relaxed sensitivity requirement:

***LPF*:**

$$S_{\Delta a}^{1/2}(\omega) = 3\times10^{-14}\left[1+\left(\frac{f}{3\ \mathrm{mHz}}\right)^2\right]\ \frac{m}{s^2}\,\mathrm{Hz}^{-1/2}\ ,\qquad 1\ \mathrm{mHz}\le f\le 30\ \mathrm{mHz}$$

Even if LTP works to top perfection, a fundamental queston remains:

How do we make it to *LISA*'s sensitivity?

Why is diagnostics analysis needed in the LTP

The methodology:

1. Split up total noise readout into parts –e.g., thermal, magnetic,...
2. Identify origin of excess noise of each kind
3. Orient future research in appropriate direction for improvement

1. Sensitive diagnostics hardware needs to be designed and built

2. a) Suitable places for monitoring must be identified.
   b) Algorithms for information extraction need to be set up.

3. Creative research activity thereafter...

Noise reduction philosophy

Problem: to assess the contribution of a given *perturbation* to the total *noise force*.

Approach: 1) Apply *controlled* perturbation $\underline{\alpha}$ to the system

2) Measure "*feed-through*" coefficient between force and perturbation:

$$F(\alpha) = \frac{\partial f_{\mathrm{int}}}{\partial \alpha}$$

3) Measure *actual* $\underline{\alpha}$ with suitable sensors

4) Estimate contribution of $\underline{\alpha}$ by *linear interpolation*:

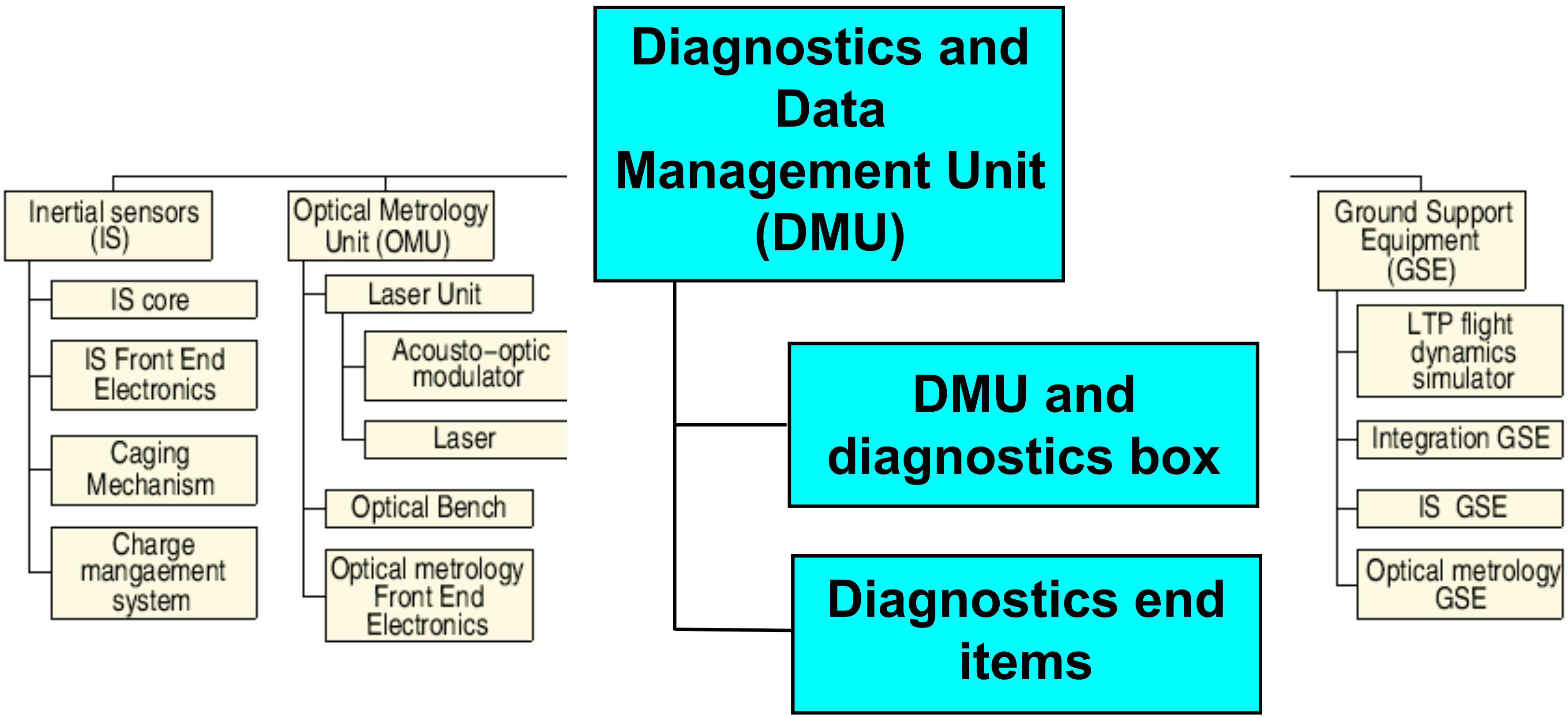
$$f_{\mathrm{int}}(\alpha) = F(\alpha)\alpha$$

5) *Substract out* from total detected noise:

$$f_{\mathrm{red}} = f_{\mathrm{int}} - f_{\mathrm{int}}(\alpha)$$

6) *Iterate* process for all identified perturbations

LTP functional architecture



DDS: Data Management & Diagnostics Subsystem

Diagnostics items:

- *Purpose*:
  - ***Noise split up***
- *Sensors for*:
  - Temperature
  - Magnetic fields
  - Charged particles
- *Calibration*:
  - Heaters
  - Induction coils

DMU:

- *Purpose*:
  - ***LTP computer***
- *Hardware*:
  - Power Distribution Unit (*PDU*)
  - Data Acquisition Unit (*DAU*)
  - Data Processing Unit (*DPU*)
- *Software*:
  - Boot SW
  - Application SW:
    - ✓ Diagnostics items
    - ✓ Phase-meter
    - ✓ Interfaces

Thermal and sensor requirements

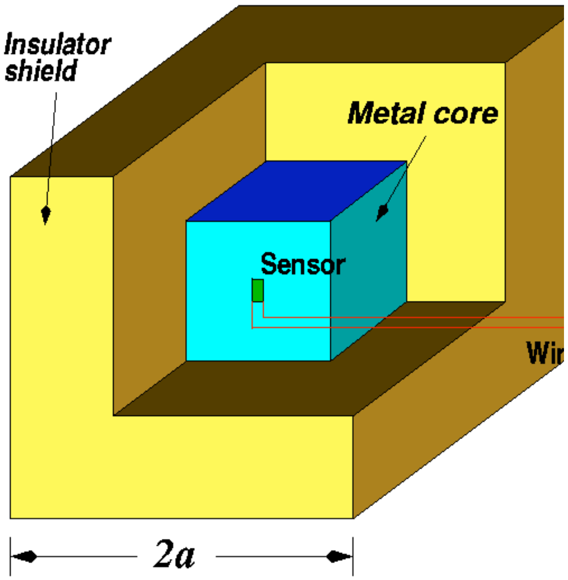
Global *LTP* stability requirement: **10^{-4} K/√Hz** , 1 mHz < *f* < 30 mHz

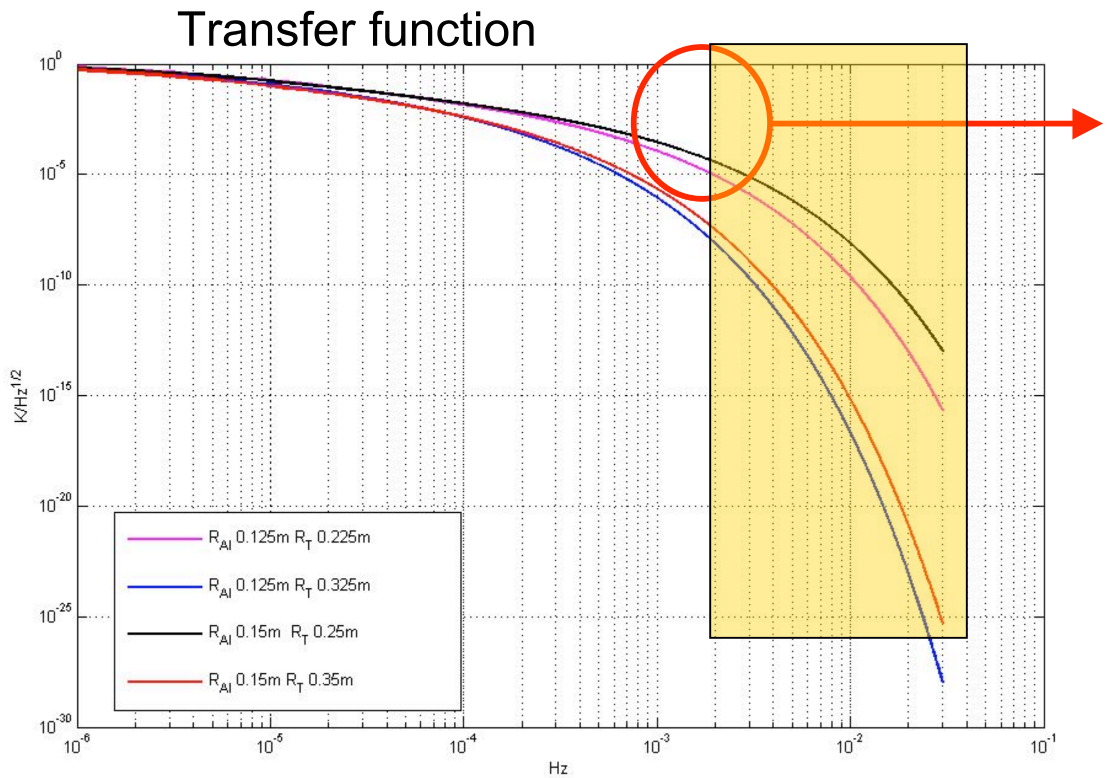
Sensor sensitivity requirement: **10^{-5} K/√Hz** , 1 mHz < *f* < 30 mHz

Location	*Number*	*Comments*	*Req. No*
Optical Bench	**4**	On locations TBC	**3.1**
Optical Windows	**4**	2 per OW	**3.2**
Inertial Sensors	**8**	2 on each of the outer x-faces of the IS EH	**3.3**
LCA mounting struts	**6**	1 per strut, near centre (TBC)	**3.4**
Total	**22**	---	---

Test campaign

- **Thermal jig**





For:

R_{al}=0.125 m

R_{total}=0.325 m

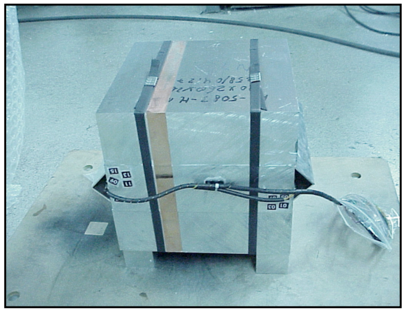
$$H(f)\big|_{f=1\ mHz} = \mathbf{8.75\,?\,10^{-7}}$$

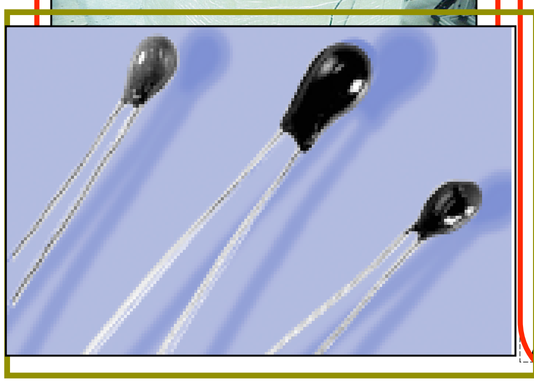
Test campaign

Faraday and Anechoic chamber (UPC facilities)

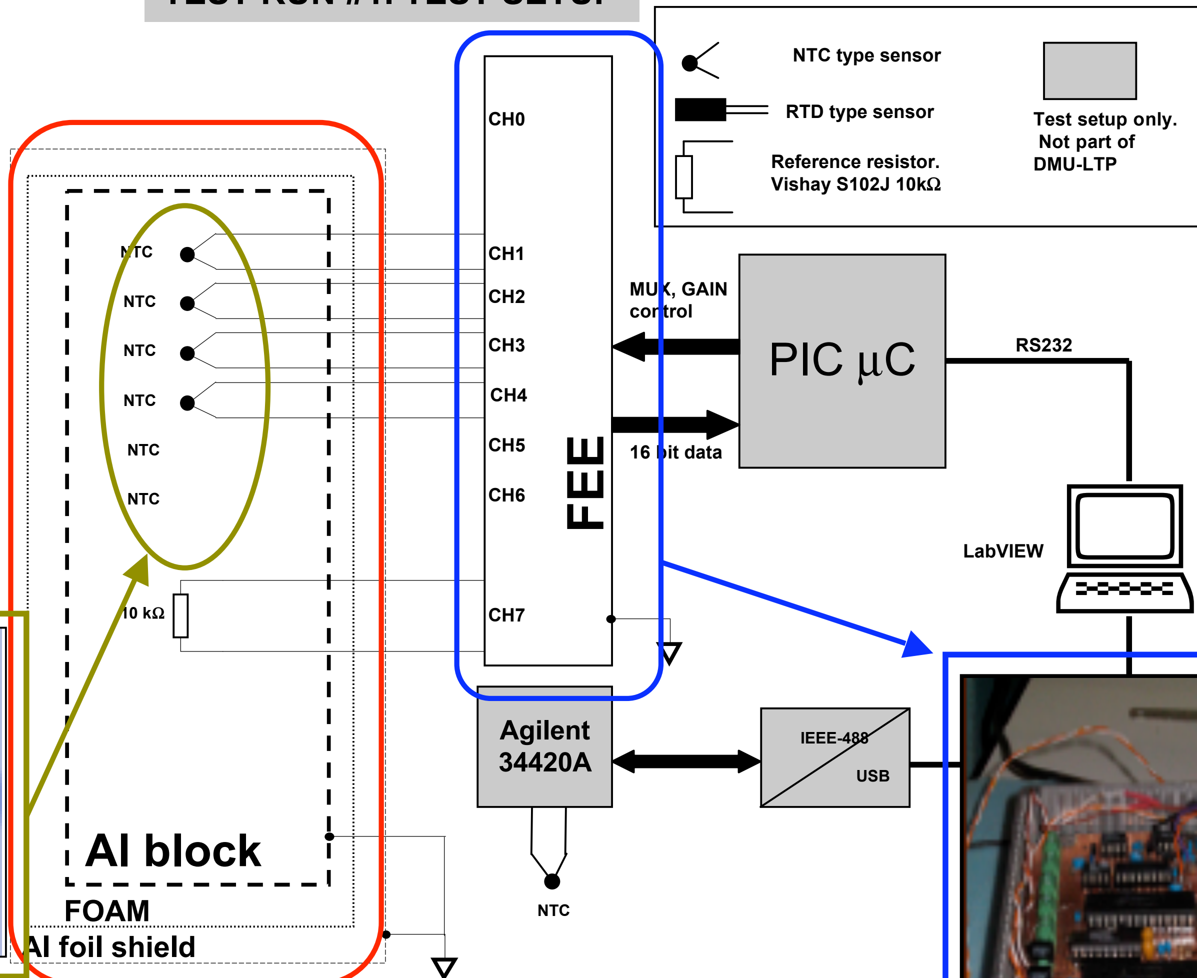
Test campaign

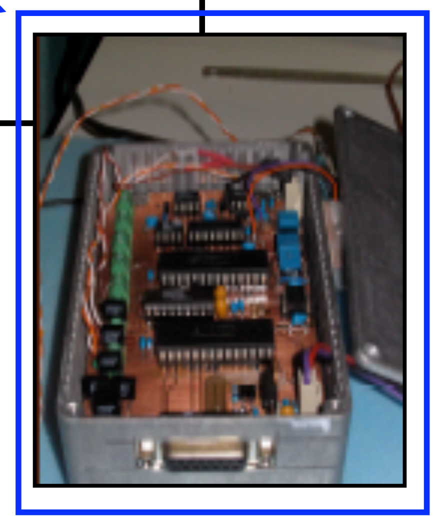
10kΩ Thermistor
(YSI 44006)





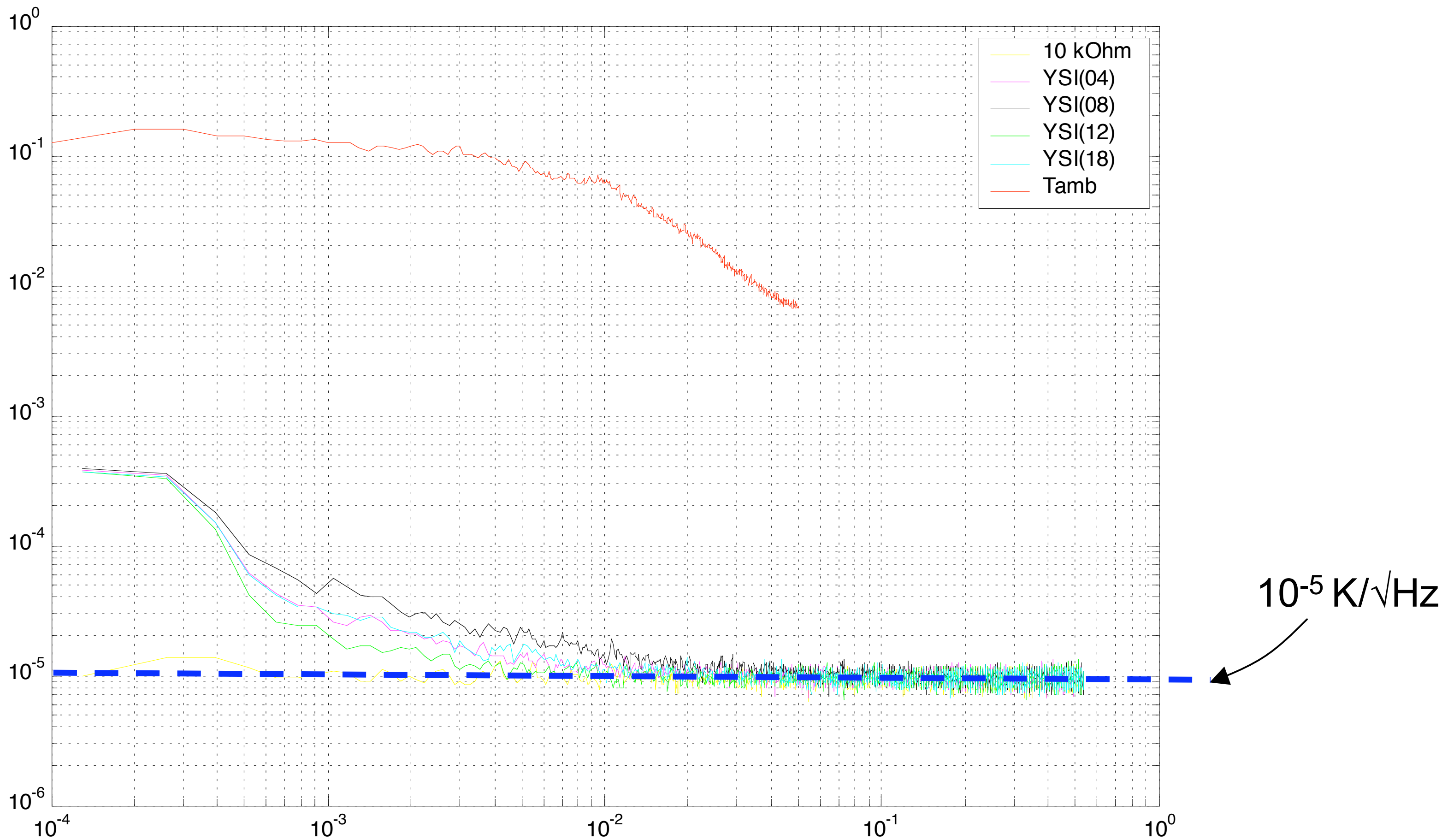
TEST RUN #1. TEST SETUP





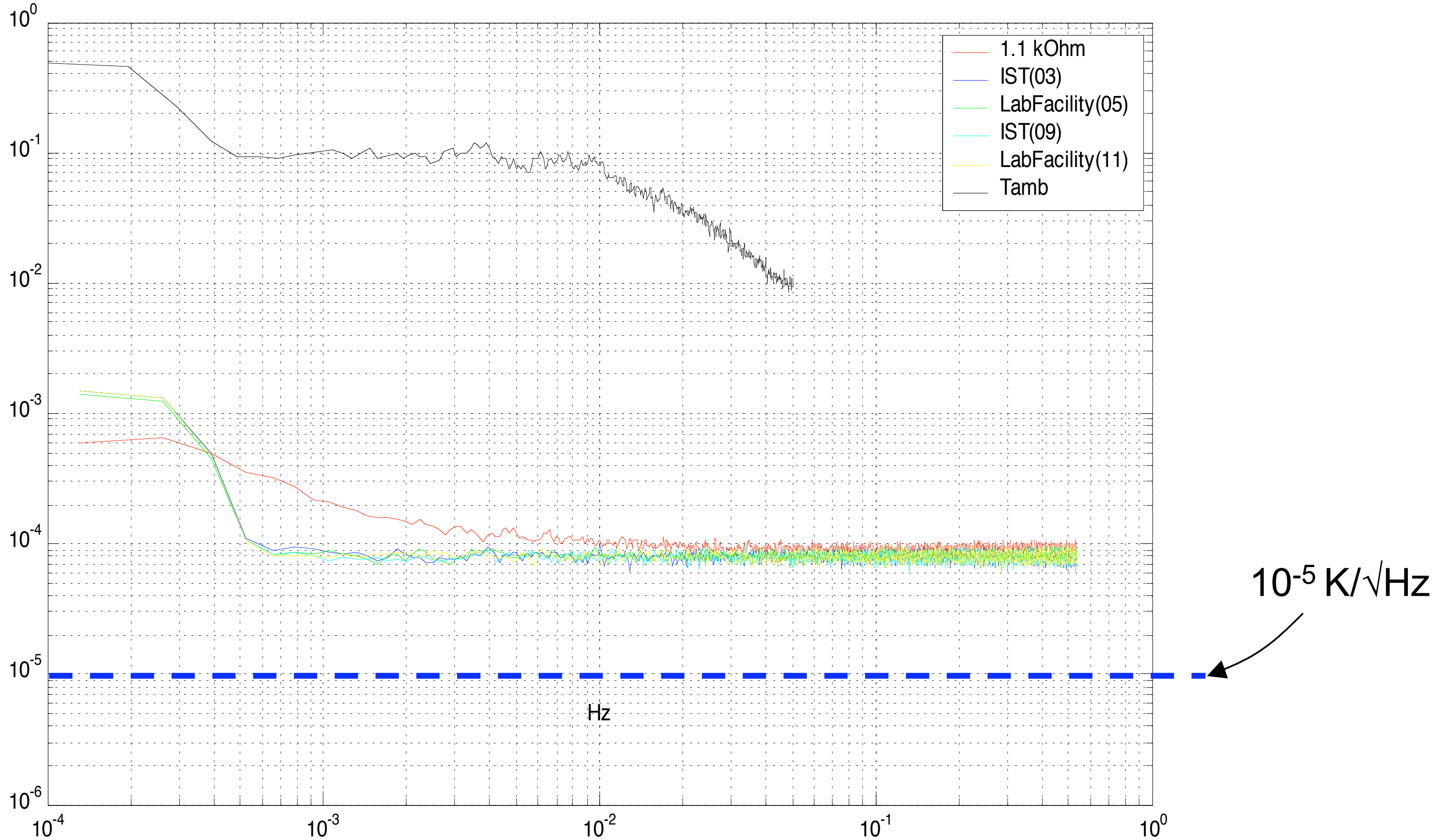
Test campaign

- Test run#1 results (**Thermistor**)
  - Power spectral density



Test campaign

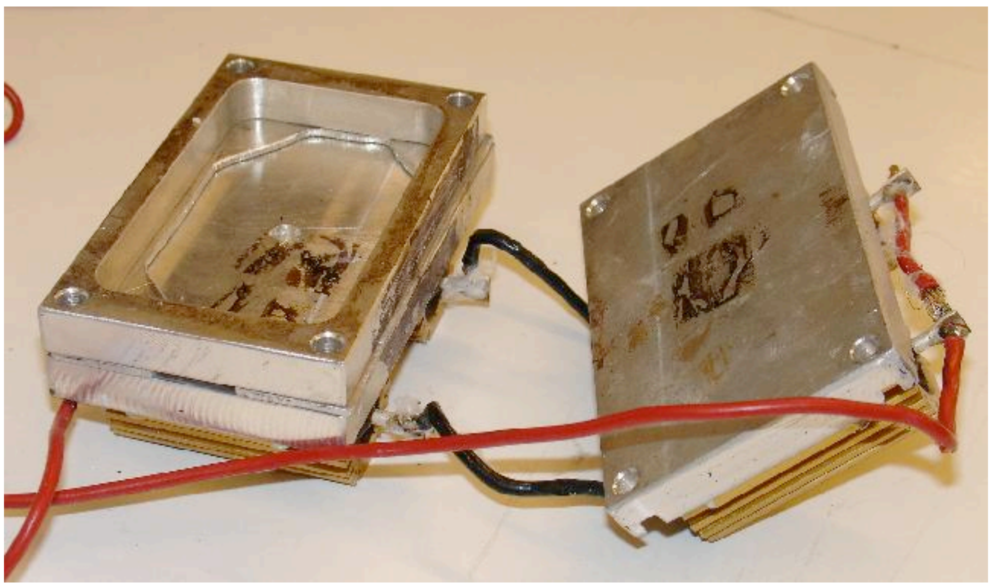
- Test run#2 results (**PRTD**)
  - Power spectral density

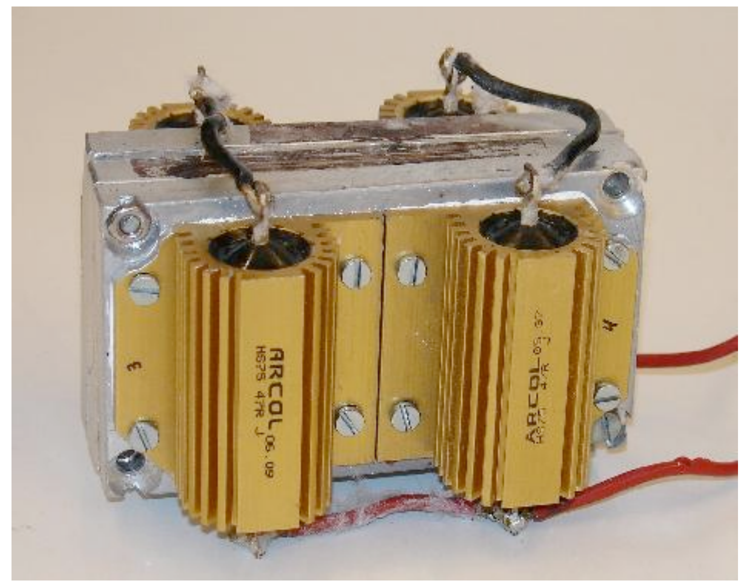


Baking test

To prevent outgassing, a baking process is foressen for ISHs:

150° C for a few days, up to a week, maximum





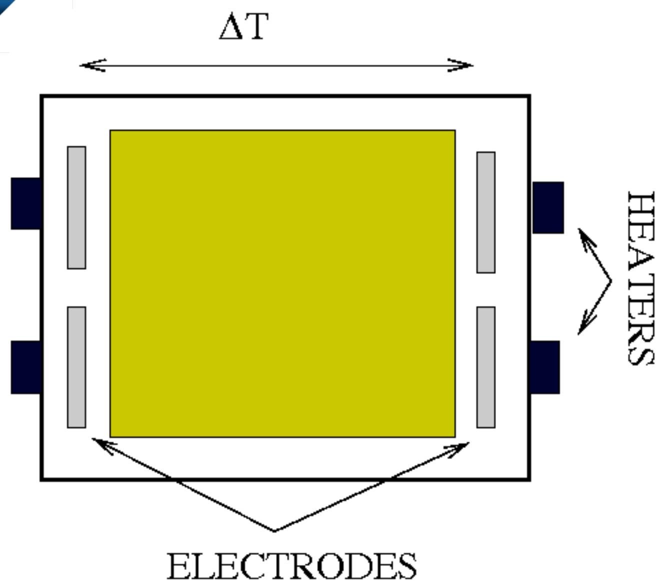
Devices are testd and in place, ready for processing

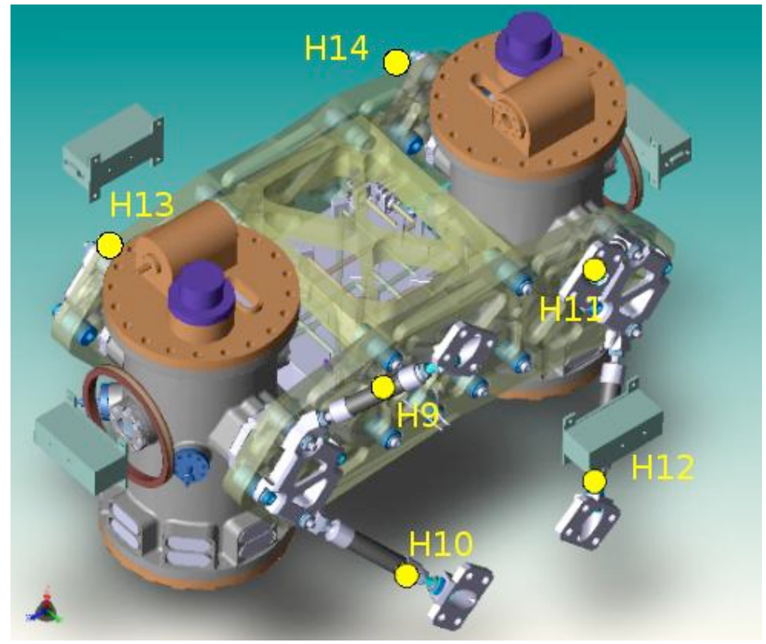
Heaters

Heaters will be used to measure thermal feedthroughs

Location	*Number*	*Maximum peak to peak temp. variation within MBW*	*Comments*	*Req. No.*
Optical window	**4**	100 mK as detected by closest sensor	2 per window	**3.6**
Inertial sensors	**4**	10 mK on inner x-faces of EH	1 on each outer x-face of EH	**3.7**
Suspension struts	**6**	100 mK (TBC) as detected by closest sensor	1 per strut	**3.8**
TOTAL	**14**		**---**	**---**

Heaters





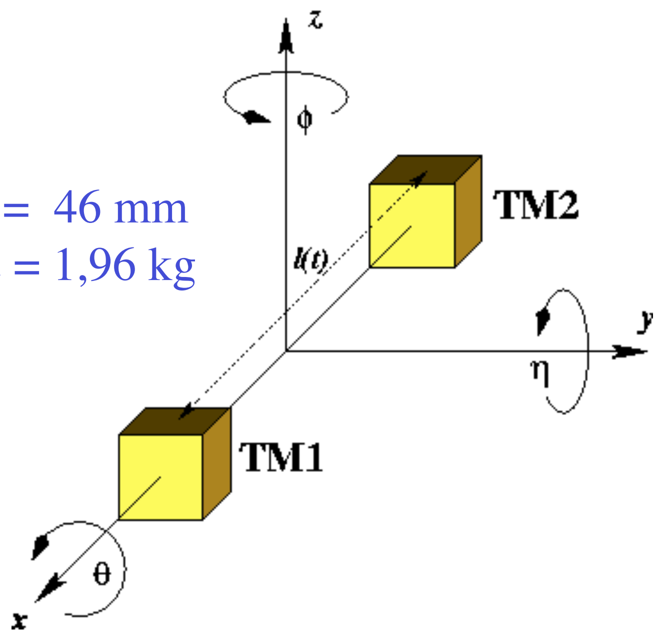
Refer to poster presentation by **Miquel Nofrarias**

Magnetic disturbances in the LTP

Main problem is *magnetic noise*. This is due to various causes:

- Random fluctuations of magnetic field and its gradient
- DC values of magnetic field and its gradient
- Remnant magnetic moment of TM and its fluctuations
- Residual high frequency magnetic fields

$a = 46$ mm
$m = 1{,}96$ kg



Test masses are a AuPt alloy

70% Au + 30% Pt

of low susceptibility

$$|\chi| \leq 10^{-5}$$

and low remnant magnetic moment:

$$|\mathbf{m}_0| \leq 10^{-8}\ \mathrm{A\,m}^2$$

Quantification of magnetic effects

If a magnetic field $\mathbf{B}$ acts on a small volume d^3x with remnant magnetisation $\mathbf{M}$, and susceptibility χ, the force on this small volume is:

$$\frac{d\mathbf{F}}{d^3x} = \nabla\left[\left(\mathbf{M} + \frac{\chi}{2\mu_0}\mathbf{B}\right)\cdot\mathbf{B}\right] = \left[\left(\mathbf{M} + \frac{\chi}{\mu_0}\mathbf{B}\right)\cdot\nabla\right]\mathbf{B}$$

Total force requires integration over TM volume, or:

$$\mathbf{F} = \left\langle\left[\left(\mathbf{m}_0 + \frac{V\chi}{\mu_0}\mathbf{B}\right)\cdot\nabla\right]\mathbf{B}\right\rangle$$

Most salient feature is ***non-linearity of force dependence*** on $\mathbf{B}$.

Summary of magnetic requirements

Magnitude	Value
DC magnetic field	10 μT
DC magnetic field gradient	5 μT/m
Magnetic field fluctuation rms *PSD*	650 nT/√Hz
Magnetic field gradient rms *PSD*	250 (nT/m) /√Hz
Magnetic susceptibility	10^{-5}
Remnant magnetic moment	10^{-8} Am^2

Magnetic sensor requirements

Req 2: A minimum 4 magnetometers.

Req 2-1: Resolution of 10 nT/sqrt(Hz) within MBW.

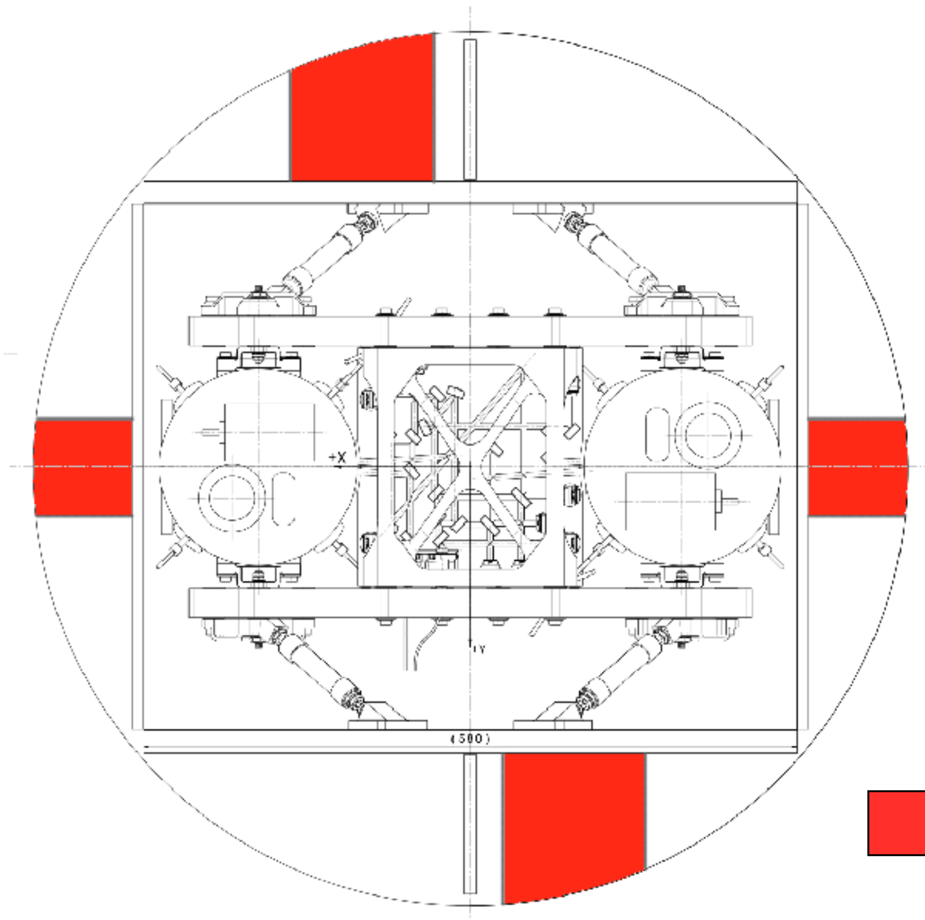
Req 2-2: Two magnetometers located along x-axis, each as close as possible to the centre of one of the TM, not farther than 120 mm.

Req 2-3: The other two may be offset from the x-axis by an amount not larger than 120 mm (TBC), their x coordinate should fall between the IS's at distances TBC.

Req 2-4: Operation of magnetometers compatible with full science performance.

Req 2-5: Final exact choice of magnetometer locations depends on final configuration of magnetic sources. Limited adjustment of magnetometer positions to within +/- 10 cm along x, y and z must be allowed until system CDR.

Magnetometer layout



Current proposal:

- 4 Flux-gate magnetometers

The adopted baseline is **four** 3-axes magnetometers, model **TFM100G2** from *Billingsley Magnetics*.

Areas for magnetometer accommodation

Magnetic field sources

According to data provided by *ASU* (Dave Wealthy), identified magnetic sources fall into three groups:

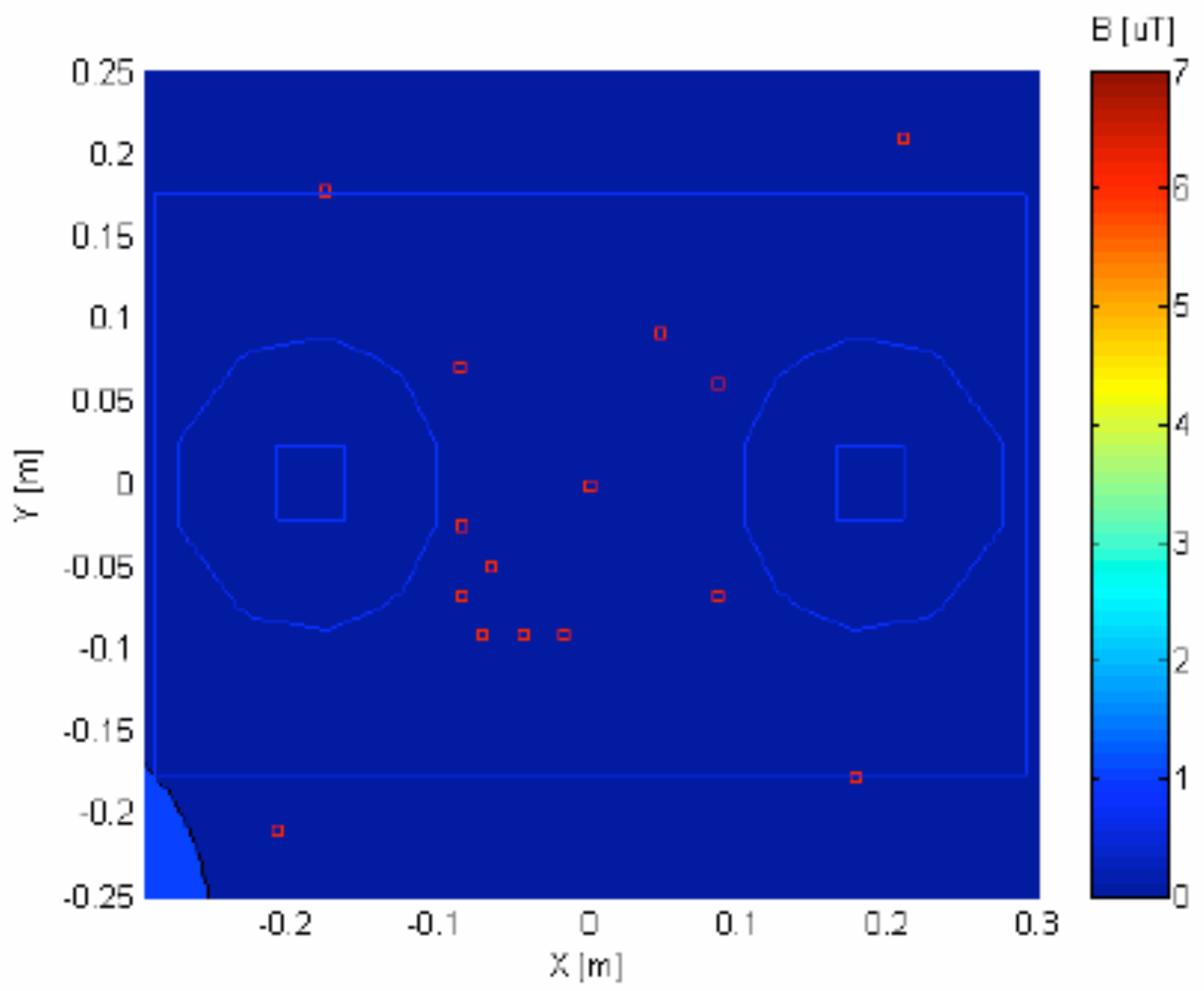
- Spacecraft sources
- LTP sources
  - Peripheral
  - Inside LCA
- ~~DRS sources~~
- Sources associated to new structures?

Magnetic field reconstruction

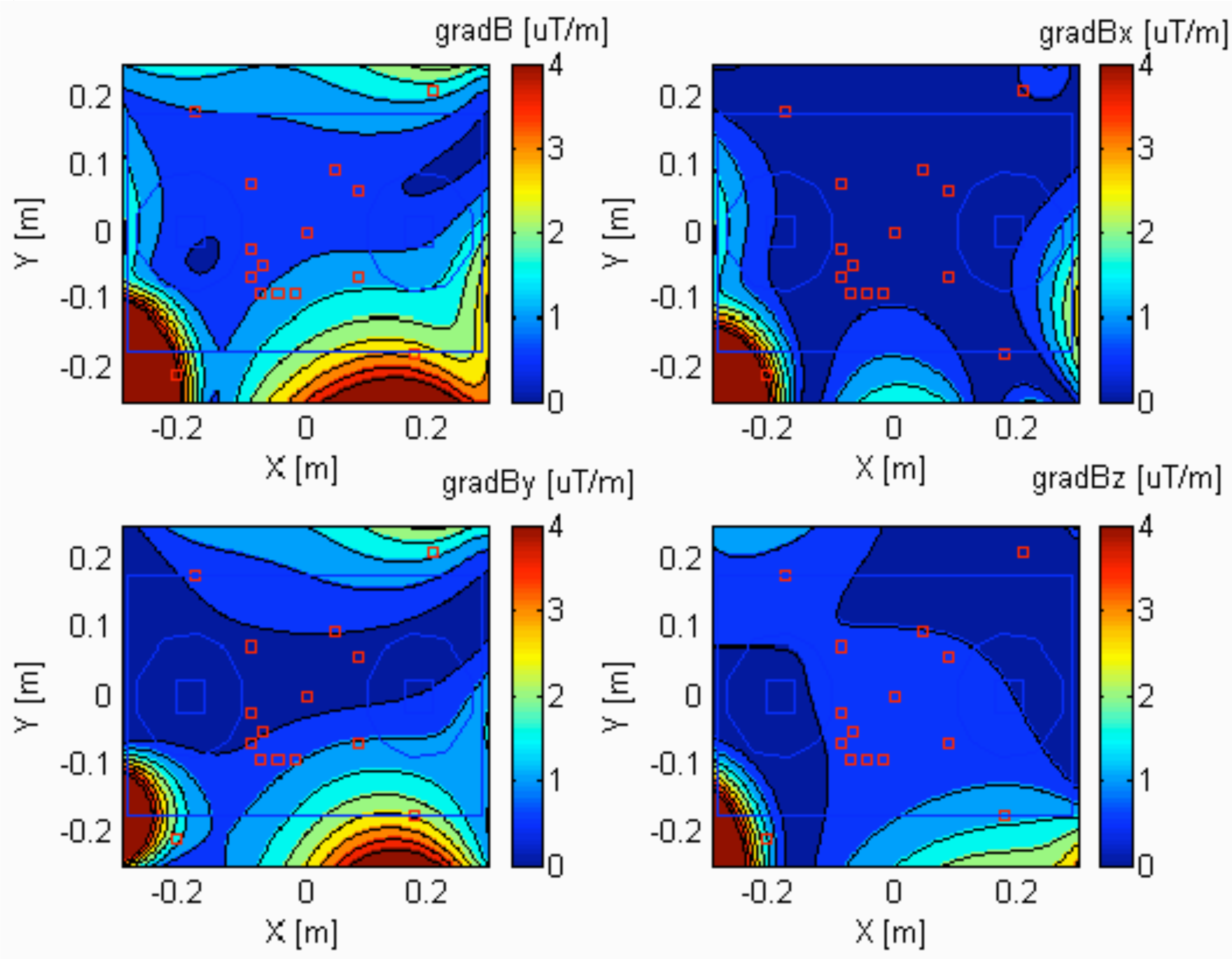
Current status:

- Sources are clearly identified
- They are mostly Electronics Boards
- Magnetic moment direction is fixed
- Only *moduli* are unknown
- This gives good room for accurate estimates
- Any excess magnetic fields are readily detectable
- Detailed field reconstruction is an *off-line task*, not critical at this time
- There's room for perfectioning and fine-tuning analysis techniques

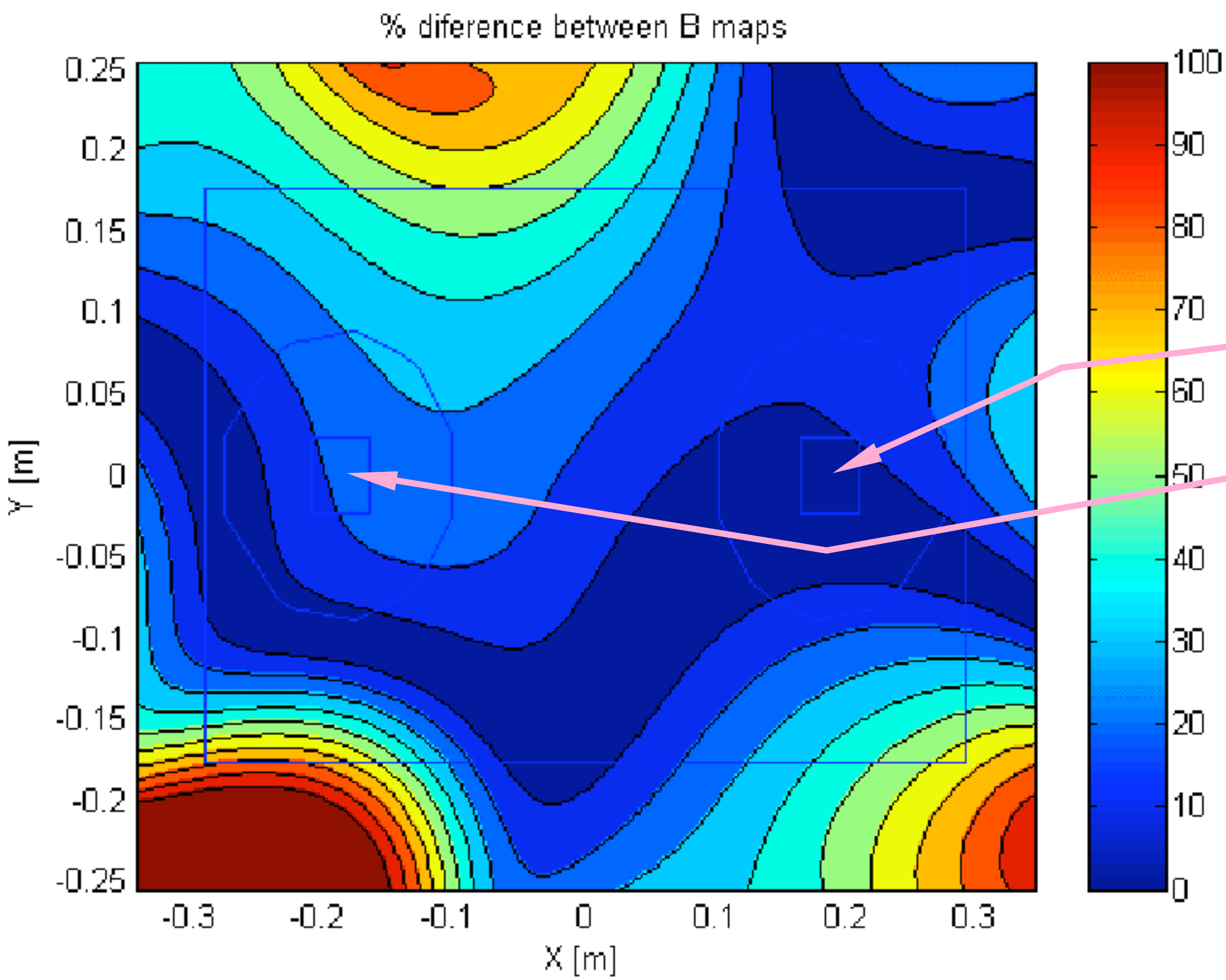
Magnetic field maps I



Magnetic field maps II



Magnetic field maps III: Reconstruction errors



Error is:

- Well below **10%** in TM2
- Between **10%** and **20%** in TM1

Almost an order of magnitude improvement over previous estimates!

Control coils

Philosophy: to apply controlled periodic magnetic fields:

$$\mathbf{B} = \mathbf{B}_{\rm ext} + \mathbf{B}_{\rm app} \; ; \qquad \mathbf{B}_{\rm app}(\mathbf{x},t) = \mathbf{B}_0(\mathbf{x})\, e^{i\omega t}$$

Force comes then a two frequencies:

$$\mathbf{F} = \mathbf{F}_{\omega} + \mathbf{F}_{2\omega}$$

$$\mathbf{F}_{\omega} = \left\langle (\mathbf{m}_0 \cdot \nabla)\mathbf{B}_{\rm app} \right\rangle + \frac{V\chi}{\mu_0} \left\langle (\mathbf{B}_{\rm ext} \cdot \nabla)\mathbf{B}_{\rm app} + (\mathbf{B}_{\rm app} \cdot \nabla)\mathbf{B}_{\rm ext} \right\rangle$$

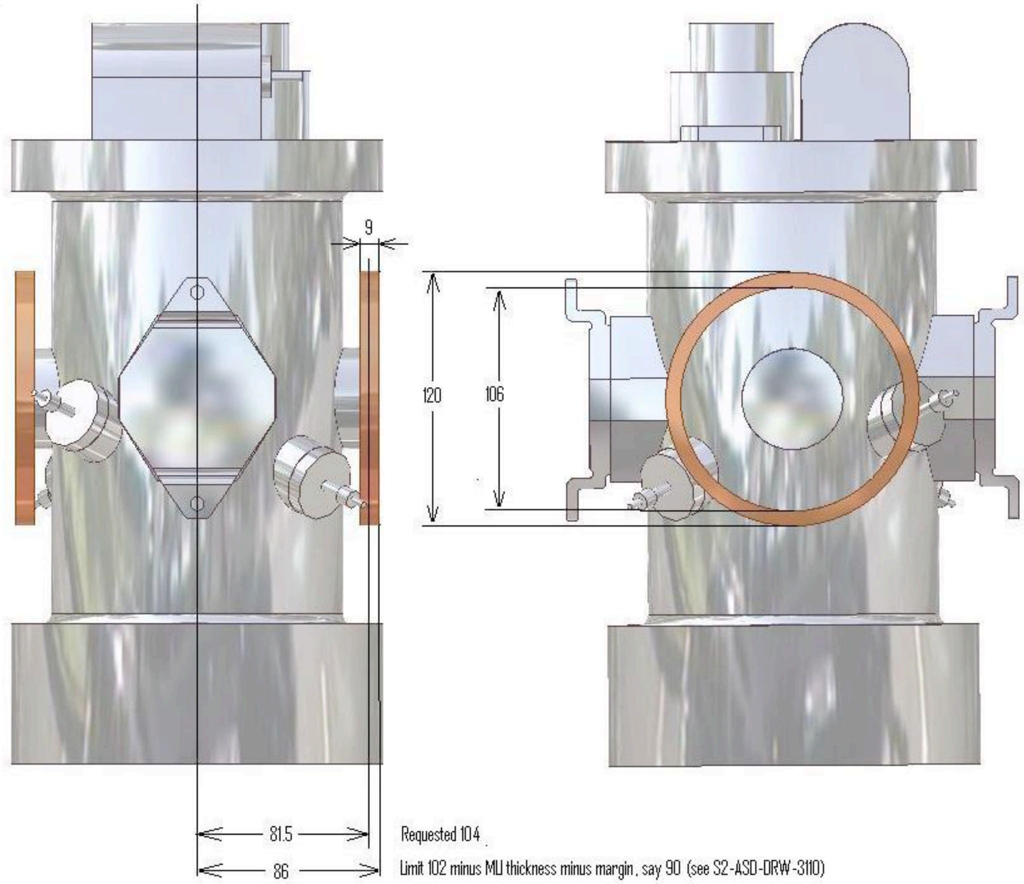
$$\mathbf{F}_{2\omega} = \frac{V\chi}{\mu_0} \left\langle (\mathbf{B}_{\rm app} \cdot \nabla)\mathbf{B}_{\rm app} \right\rangle \longrightarrow$$

measure χ

($\omega \sim$ 1 mHz)

Coils must be long (2400 turns), to maintain reduced heat dissipation (~few mW).

Control coils

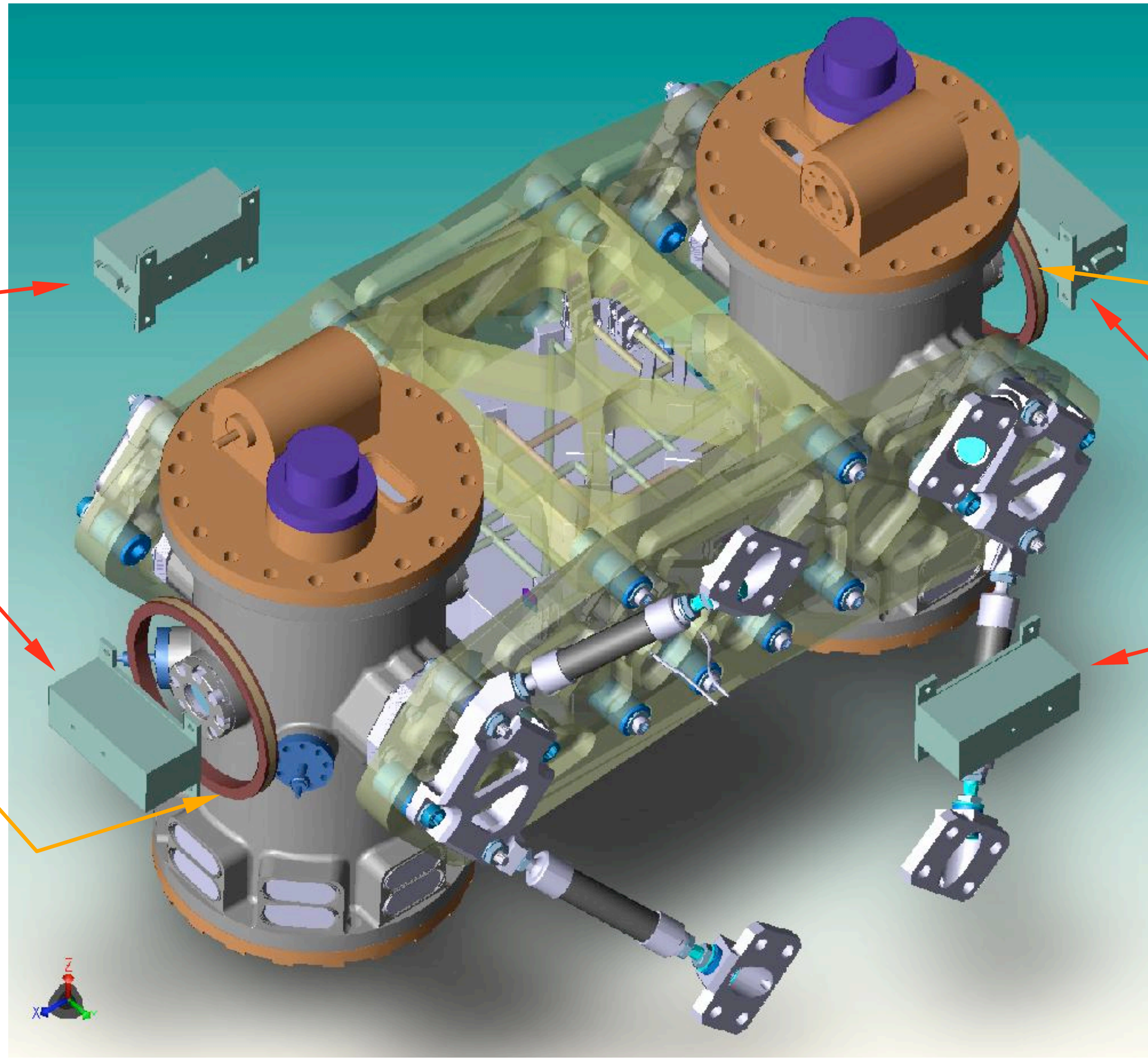


Purpose:

- To measure χ in flight
- To measure **M** in flight
- To drive magnetic noise

Coils must comply with suitable reqs. of power and stability.
Test plan is written, and test will be done shortly.

General *LTP* layout



Radiation Monitor

Ionising particles will hit the *LTP*, causing spurious signals in the *IS*.

These are mostly protons (~90%), but there are also He ions (~8%) and heavier nuclei (~2%).

Charging rates vary depending on whether

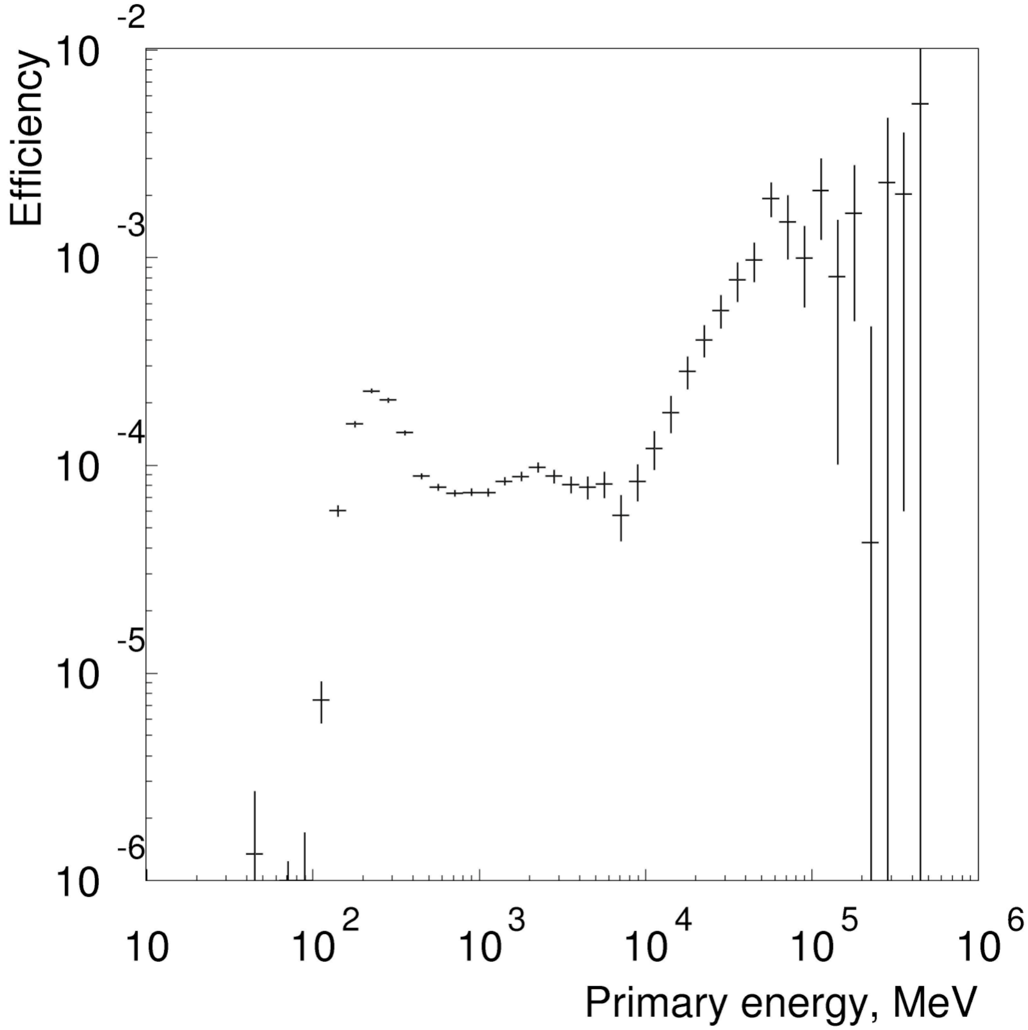
- Galactic Cosmic Rays (*GCR*), or
- Solar Energetic Particles (*SEP*)

hit the detector, as they present different energy spectra.
This has been shown by extensive simulation work at *ICL*.

Therefore a *Radiation Monitor* should provide the ability to distinguish *GCR* from *SEP* events.

This means **RM needs to determine energies** of detected particles.

Radiation Monitor



ICL simulations, based on GEANT-4.

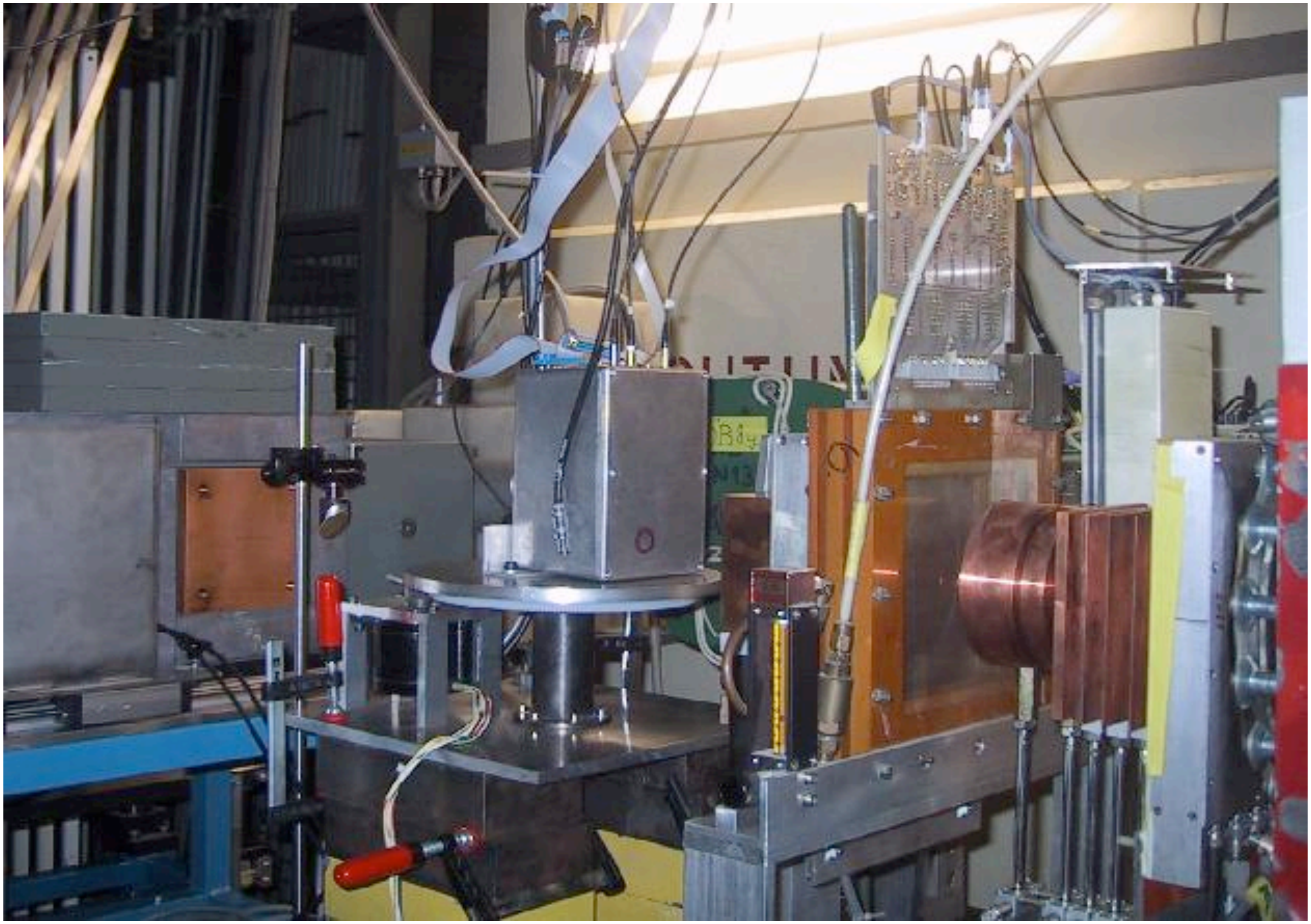
(Peter Wass and Henrique Araujo)

LTP Radiation Monitor

It is a particle counter with some specific capabilities:

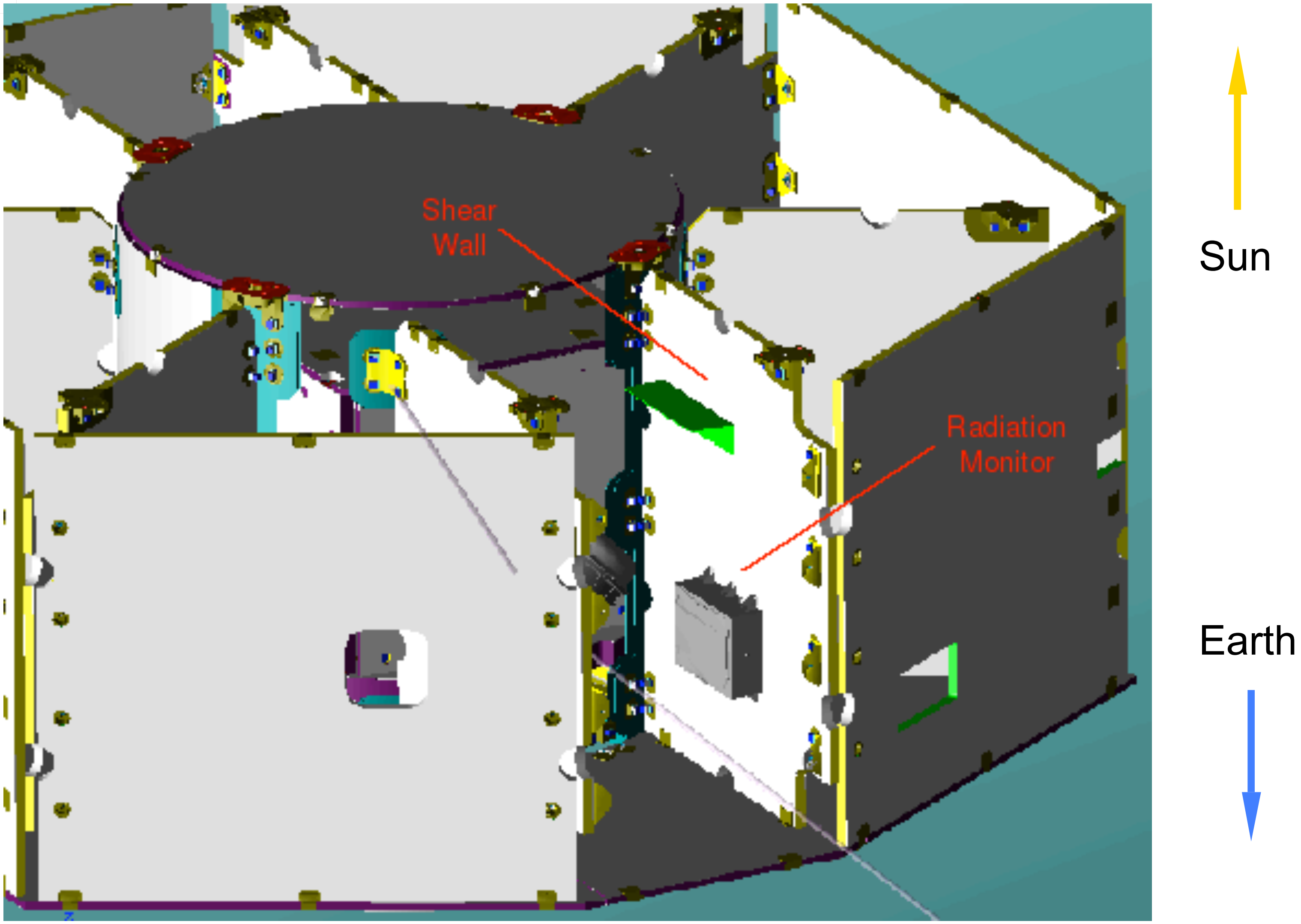
- It counts particle hits
- Retrieves spectral information (coincident counts)
- Can (statistically) tell GCR from SEP events
- Electronics is space qualified

In place for test at *PSI*, Nov-2005



In place for test at *PSI*, Nov-2005

RM accommoation in S/C



DMU

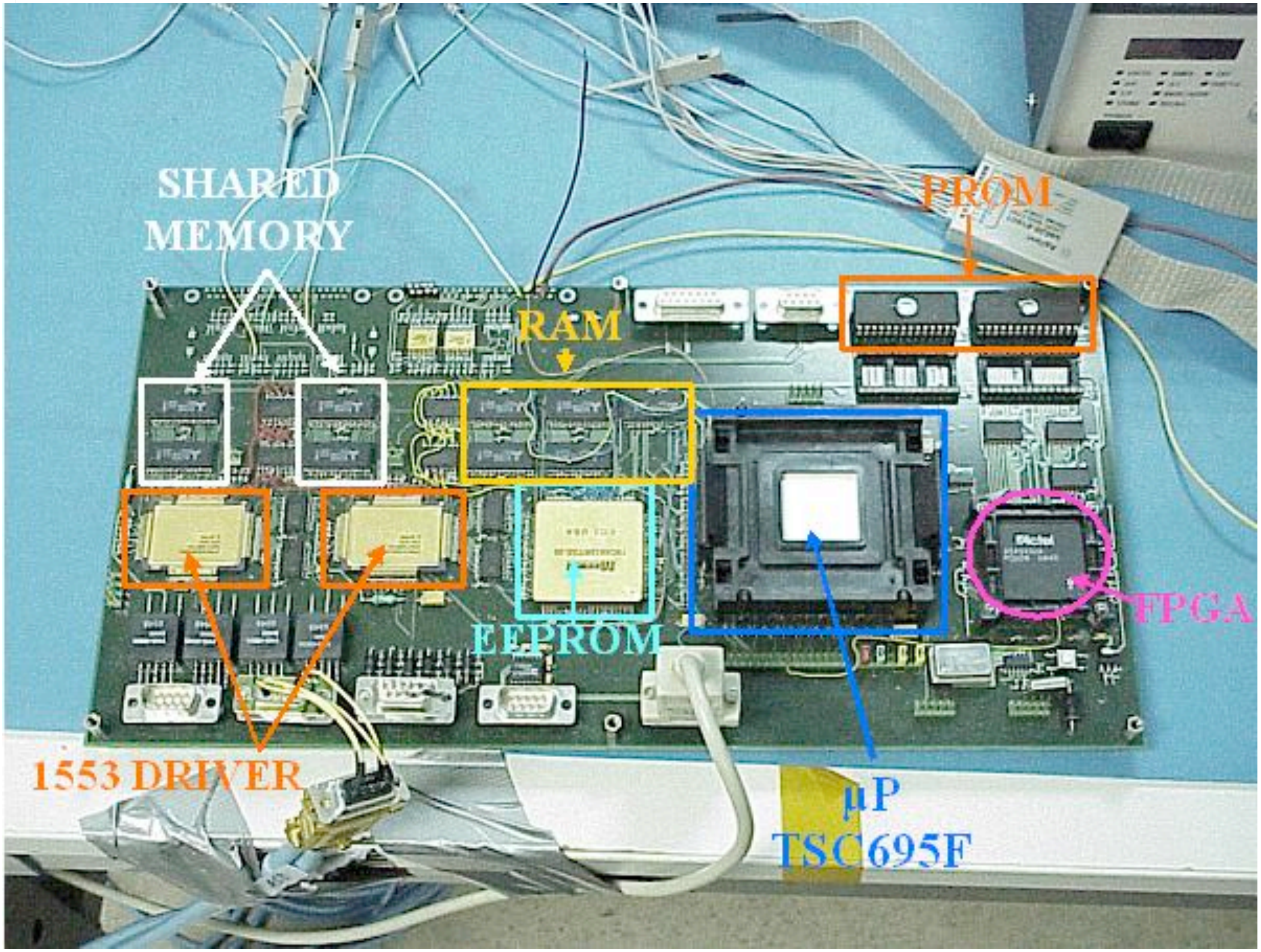
Purpose:

- ***LTP computer***

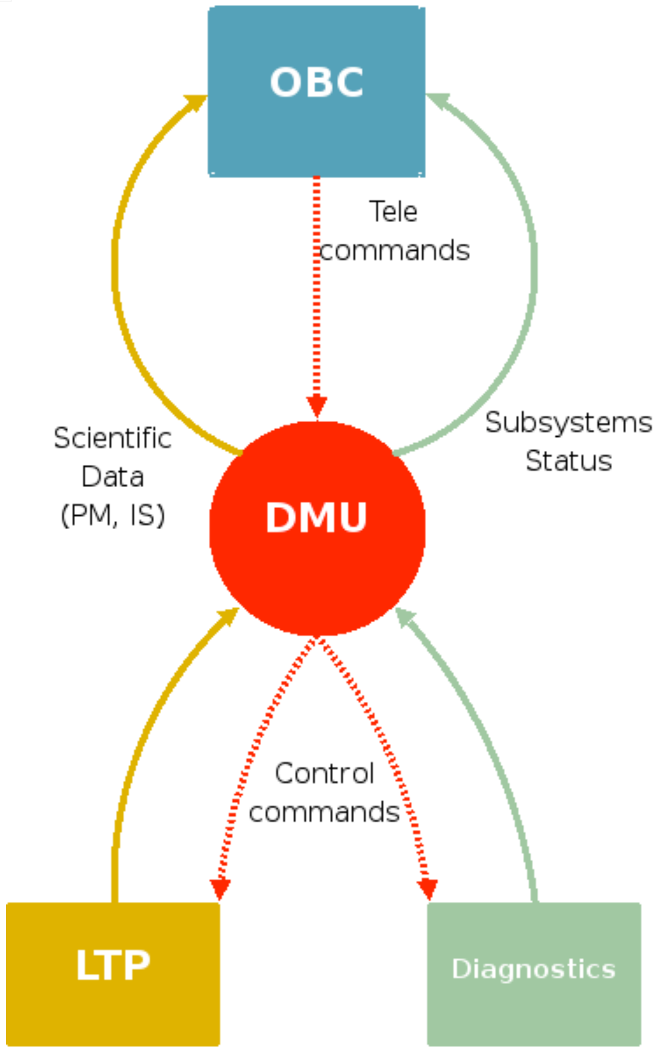
- *Hardware*:
  - Power Distribution Unit (*PDU*)
  - Data Acquisition Unit (*DAU*)
  - Data Processing Unit (*DPU*)

- *Software*:
  - Boot SW
  - Application SW:
    - ✓ Diagnostics items
    - ✓ Phase-meter
    - ✓ Interfaces

***DPU* board**



DMU software



Goals:

- M&C of *LTP* subsystems
- Delivery of science data
- Remote *LTP* control from OBC/Ground

Refer to poster presentation by **Jose Antonio Ortega**

Conclusion

- *DDS* is a key tool for debugging noise sources in *LTP*
- This should help clarify route of sensitvity improvement for *LISA*

- *DDS* design is mostly complete
- *PDR* was almost successful in September-2005
- δ-*PDR* will be (hopefully) successful next month (July-2006)
- Flight Hardware production will subsequently start
- Flight Software is already being written
- Data analysis techniques and algorithms for useful exploitation of *DDS* are being developed
- Joint work with various Institutes and industry